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Independence of calibration curves for EBT Gafchromic films of the size of high-energy X-ray fields

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Abstract

The EBT Gafchromic radiochromic film is a relatively new product designed specifically for dosimetry in radiation therapy. Due to the weak dependence of its response on the photon energy (variations are below 10% in the 50 kVp–10 MVp range), the film is ideal for dosimetry when the photon energy spectrum may be changing or unknown. In order to convert a map of optical densities into a map of absorbed radiation doses, a calibration curve constructed on the basis of standard calibration films is necessary. Our results have shown that, with the EBT Gafchromic film, one can use the same calibration curve for 6-MV X-ray fields of any size in the range from $5 \times 5\,cm^2$ up to $40 \times 40\,cm^2$. This is not the case for radiographic films, such as Kodak X-Omat V, whose response to the same dose varies approximately by 10% depending on the field size in this range. This insensitivity of the EBT Gafchromic film to size of the radiation field makes it possible to assess doses delivered by small radiation fields. With the help of this film, it was shown that the output factor for a $0.5 \times 0.5\,cm^2$ field is 0.60 ± 0.03 (2SD) relative to the $10 \times 10\,cm^2$ field.

Keywords: Radiochromic film; Gafchromic; EBT; Calibration; Energy dependence; Field size; Scatter; Radiotherapy

1. Introduction

Over the years, two-dimensional dosimetry in radiotherapy has been performed primarily with films (Palm and LoSasso, 2005; Butson et al., 2004, 2005b; Suchowerska et al., 1997; Tangboonduangjit et al., 2004). This type of dosimetry requires construction of calibration curves, which are then used to convert measured optical densities into radiation doses. In the past, this was performed with silverhalide radiographic films, which exhibit a strong photon energy dependence of their response to doses (Kron et al., 1998) and are, therefore, not ideal. As treatment parameters, such as field size, change, so does the X-ray spectrum at the target, because of the changed scattering conditions. As a result, film calibration was a formidable task requiring construction of multiple calibration curves for radiation fields of different sizes. Radiochromic films in general exhibit weaker energy dependences than radiographic films because they do not contain silver (Butson et al., 2005a; Cheung et al., 2004). Response to a dose of a relatively new dosimetric film, Gafchromic EBT, varies by less than 10% in the wide range between 50 kVp and 10 MVp (Butson et al., 2006), which should significantly simplify the calibration procedure. It should also make it possible to measure small field output factors accurately (Westermark et al., 2000; Martens et al., 2000; Laub and Wong, 2003), thus providing a ‘‘point’’ dosimeter. In this work, we have investigated dependence of the response of this film to the same doses delivered by fields of different sizes.

2. Materials and methods

Studies of the effect of the X-ray field size on dose calibration curves were performed with the EBT Gafchromic radiochromic film in comparison with the Kodak X-Omat V radiographic film. EBT films are multilayered:

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the active polymer is protected by polyester coatings, which allows the film to be handled easily and minimizes ultraviolet exposure of the active polymer (Butson et al., 1998, 2003). The effective atomic number of the EBT film (Z_{eff}) is 6.98, which is not very far away from Z_{eff} for water (7.3) (ISP web site, 2005). Because of this similarity and the relatively weak energy dependence of the film response to dose, one can expect that the effect of the field size on calibration curves (optical density vs. dose) will be small or even negligible, provided that the energy of the X-rays in the beam does not change and is relatively high. The films were irradiated in a solid water (Constantinou et al., 1982) phantom ($30 \times 30 \times 30\,\text{cm}^3$), which rested on the linear accelerator couch (SSD = 100 cm). The films were given the same number of monitor units (approximately 3 Gy). The delivered dose depended on the used field size, which ranged from $5 \times 5\,\text{cm}^2$ to $40 \times 40\,\text{cm}^2$. The analysis of the EBT radiochromic films was delayed until at least 6 h after the irradiation in order to minimize effects of post-irradiation coloration (Cheung et al., 2005). The Gafchromic films were analyzed with a flatbed computer scanner (Hewlett Packard ScanJet) and the Image J software. The scanning resolution was 75 pixels per inch, and the images were stored in the 16-bit RGB format. The colors were not separated, and the full RGB values were used in the analysis.

Experiments with the Kodak X-omat V film were similar. The films were irradiated to smaller doses (approximately up to 66 cGy) according to the range of their sensitivity. The films were analyzed on a VidarVX-12 fluorescent light scanner.

For both the types of the films, net OD values were plotted vs. radiation doses.

Experiments were also performed to evaluate relative output values of the EBT Gafchromic film for small fields (down to $0.5 \times 0.5\,\text{cm}^2$). The results were compared with measurements performed with small-volume and standard-volume ionization chambers.

3. Results and discussion

Fig. 1a shows calibration curves for EBT Gafchromic film exposed to 6-MV X-ray radiation fields of various sizes, ranging from $5 \times 5\,\text{cm}^2$ to $40 \times 40\,\text{cm}^2$. For any given dose, variation of the optical density over this range of field sizes is very small and insignificant as compared with the uncertainties of film analysis (~3%). Irradiations to the same number of monitor units, but with increasing field size, result in increasing doses because of the increasing scatter. These results are very interesting because they show that a single calibration curve can be used for processing of all radiochromic films of this type regardless of the sizes and configurations of the radiation fields used for their irradiation. This can be particularly useful for analysis of small fields, individual calibration curves for which are hard to produce. A standard calibration curve constructed with a $10 \times 10\,\text{cm}^2$ field can be used for analysis of doses

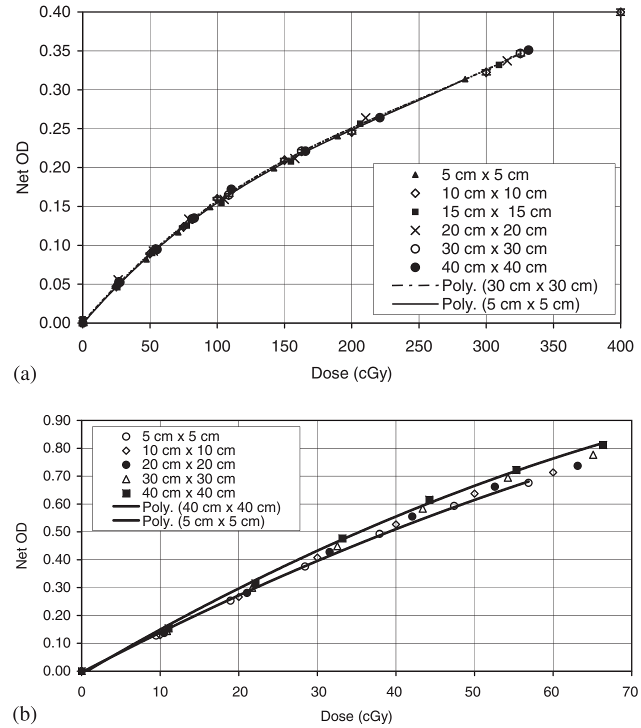

Fig. 1. Standard calibration curves for assessing doses in radiation fields of various sizes: (a) EBT Gafchromic radiochromic film; (b) Kodak X-omat V radiographic film. Second order polynomials are used to fit data.

delivered with small fields, like those used in intensity-modulated radiation therapy (IMRT). For comparison, Fig. 1b shows a similar set of calibration curves for the Kodak X-Omat V radiographic film, although for lower doses appropriate for the sensitivity range of that film. One can see a measurable difference between the calibration curves for fields of different sizes: larger fields produce higher net optical densities for the same dose. This is not surprising because increasing radiation field changes the X-ray spectrum: the lower-energy X-rays become more intense due to the increased scatter. As the energy dependence of the response of the radiographic film to a dose is significantly stronger in the lower-energy range, one should expect a higher optical density per unit dose for larger fields. This dependence requires that the radiation fields used in construction of the calibration curve and in experiments using the curve would be of the same size. It also means that radiographic film is not ideal for relative dosimetry in situations where the radiation spectrum may vary, e.g. at beam edges. EBT Gafchromic film has minimal field-size effects and is, therefore, superior for film calibrations.

Fig. 2 shows the dependence of the dose output on the size of a 6-MV X-ray field measured by different techniques. The EBT Gafchromic film results are shown for fields down to $0.5 \times 0.5\,\text{cm}^2$, where the relative field output factor was found to be 0.60 ± 0.03 (2SD). EBT seems to be a nearly ideal detector for small field measurements as its spatial resolution is very high and it